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Impacts of climate change on the body size of horse mackerel in the North Sea

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Summary

Clear biogeographic trends persist in the body sizes of individuals in marine communities, with smaller species and individuals within species found in warmer waters. Based on this trend (Bergmann's Rule), communities undergoing warming at a given location are likely to become more representative of body sizes seen in warmer waters. Using fisheries independent North Sea survey data with established catchability corrections, we investigated the effect of 30 years of warming on average size and species size distributions. We found, as an example, that horse mackerel (*Trachurus trachurus*) is consistent with Bergmann's Rule, with larger average sizes seen at higher latitudes. Over 30 years a significant decline in average size has occurred at several latitudes. Using a Eulerian (grid based) approach and dividing the North Sea into 82 1° x 1° cells, 56% of cells displayed size distributions shifting towards populations with higher proportions of smaller individuals. Changing size distribution correlated significantly with warming over the study period. Horse mackerel's northern range is in the northern North Sea, indicating populations at species range boundaries may be most affected by further warming. This finding warrants further work on a wider number of species. Changing body sizes and shifts in size distributions has implications for ecosystem functioning, trophic level dynamics and the value of fisheries.

Introduction

The shallow European continental shelf seas have experienced rapid warming at rates exceeding the global average, with warming in the North Sea 6x the mean global rate (Mackenzie and Schiedek, 2007; Sherman *et al*., 2009). A number of species responses to climate change have been observed, including alterations in spatial distributions, phenology and abundance of species within communities. Species responding positively to warming are predominantly smaller bodied Lusitanian species (Simpson *et al*., 2011), warranting a more thorough investigation into the impacts of warming on body size. Large-scale biogeographic trends pervade both terrestrial and aquatic environments and Bergmann's Rule states that average body size within species increases with latitude (Blackburn *et al*., 1999). Thus within a given geographical area experiencing warming a decline in average body size is to be expected, with body sizes becoming more representative of those found at warmer climates.

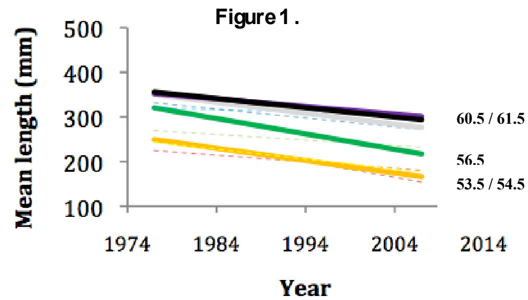
Methodology

In this study fisheries independent catch data from 1977-2007, from both the ICES IBTS and Cefas NSGFS, were analysed. Catchability corrections were applied to the raw survey hauls to provide estimates of total community assemblages per km^2. Sea Surface Temperature and Sea Bottom Temperatures were obtained from the UK Meteorological Office Hadley Centre global ocean surface temperature database (1960-2008) and Proudman Oceanographic Laboratory (1960-2004) respectively. Standardised multispecies fishing mortalities, obtained from ICES stock assessments, were used with known fishing efforts to determine fishing intensities (details in Simpson *et al*., 2011). Both maximum and average lengths of species from FishBase were analysed with respect to latitude to test for the presence of biogeographic trends. The mean sizes of 6 species were then assessed, using latitude as a gradient, over the 30-year dataset. (Only analysis for horse mackerel is presented here). A Eulerian (grid based) approach, which allows for spatial heterogeneity in both environmental and ecological conditions, was subsequently adopted. Size frequency distributions were calculated for each 1° x 1° cell and year. Temporal changes in the size distributions of each species were determined. Size distribution changes for each cell were then compared with the warming and fishing intensity trends for the same time period.

Results and Discussion

Combining FishBase metadata with fisheries independent survey data, the existence of biogeographic trends in the North Sea was confirmed. As an example, horse mackerel displayed individual trends of increasing average length with latitude (R^2 = 0.81, $p<0.05$). The existence of these underlying trends supported our hypothesis that body size may change in response to ocean warming. The temperature gradient associated with latitude, driving patterns in biogeography, suggests that in a given geographical area ocean warming will cause body sizes within a species to become more representative of sizes seen in warmer climates. Consistent with biogeographic theory and our hypothesis for impacts of warming, horse mackerel declined in average length at all significant latitudes over the 30 years (Fig. 1). During the same time period SST and SBT increased, following a similar trend ($r = 0.94$, $p<0.05$). The calculated multispecies fishing mortality increased during the 1980's then declined. Over the 30 year dataset horse mackerel displayed a shift towards higher proportions of smaller individuals in 56% of cells. 22% showed no response and 22% of cells shifted towards higher proportions of larger individuals (Fig. 2.). Comparing the change in size for each 1° x 1° cell against both the fishing and warming trends we tested the influence of both variables. The 30-year warming trend for each cell was found to correlate significantly with the change in size distribution ($r = -0.35$) (Fig. 3.), whereas the correlation with fishing trend was weaker ($r = 0.23$).

A significant correlation of rising SST with higher proportions of smaller individuals in horse mackerel populations illustrates the influence warming can have on the size structures of populations. Comparison with other species (in prep.) suggests that we are more likely to observe changes with warming in species occupying their northern range boundaries. With further increases in global SST predicted (Collins *et al.*, 2006; Meehl *et al.*, 2007) and species undergoing latitudinal shifts poleward (Perry *et al.*, 2005), the potential impacts of ocean warming on other species warrant further attention. In light of predicted ocean warming and documented species responses both previously and from our analysis we are likely to observe greater reductions in body size and populations with greater proportions of smaller individuals in the future. Changing size distributions and declines in average size may have impacts on future food security and the value of fisheries. With smaller organisms typically having lower reproductive outputs (Sheridan and Bickford, 2011) the results suggest future reductions in recruitment, affecting population growth and recovery. Understanding the impacts of changing size distributions upon marine ecosystem functioning and trophic dynamics will be vital (Sheridan and Bickford, 2011; Cheung *et al.*, 2013).



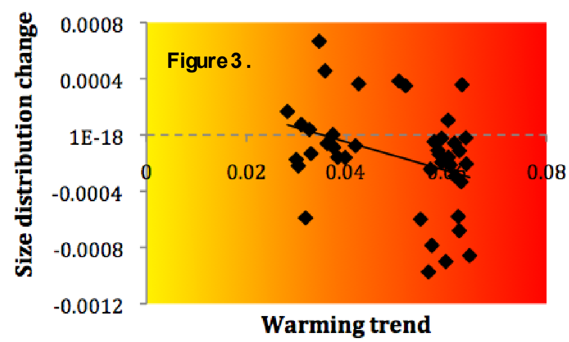


Figure 1. Change in average length (mm) for horse mackerel between 1977 and 2007 at different latitudinal belts. Figure 2. Spatial variation in size distribution change over 30 years (purple indicates decrease in size). Figure 3. Change in size distribution, per 1° x 1° cell, against the gradient of change for Sea Surface Temperature.

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